

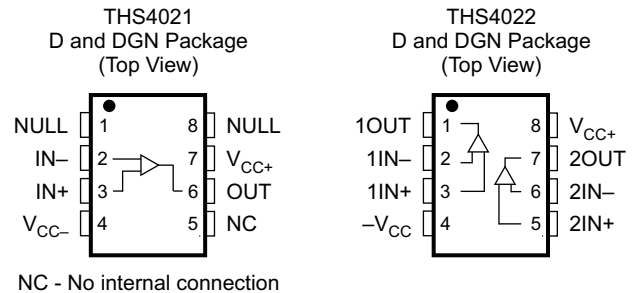
## 350-MHz LOW-NOISE HIGH-SPEED AMPLIFIERS

### FEATURES

- **Ultralow  $1.5\text{-nV}/\sqrt{\text{Hz}}$  Voltage Noise**
- **High Speed:**
  - **350-MHz Bandwidth ( $G = 10$ ,  $-3\text{ dB}$ )**
  - **470-V/ $\mu\text{s}$  Slew Rate**
  - **40-ns Settling Time (0.1%)**
- **Stable at a Gain of 10 ( $-9$ ) or Greater**
- **High Output Drive,  $I_O = 100\text{ mA}$  (typ)**
- **Excellent Video Performance:**
  - **17-MHz Bandwidth (0.1 dB,  $G = 10$ )**
  - **0.02% Differential Gain**
  - **0.08° Differential Phase**
- **Very Low Distortion:**
  - **THD =  $-68\text{ dBc}$  ( $f = 1\text{ MHz}$ ,  $R_L = 150\ \Omega$ )**
- **Wide Range of Power Supplies:**
  - **$V_{CC} = \pm 5\text{ V}$  to  $\pm 15\text{ V}$**
- **Available in Standard SOIC or MSOP PowerPAD™ Package**
- **Evaluation Module Available**

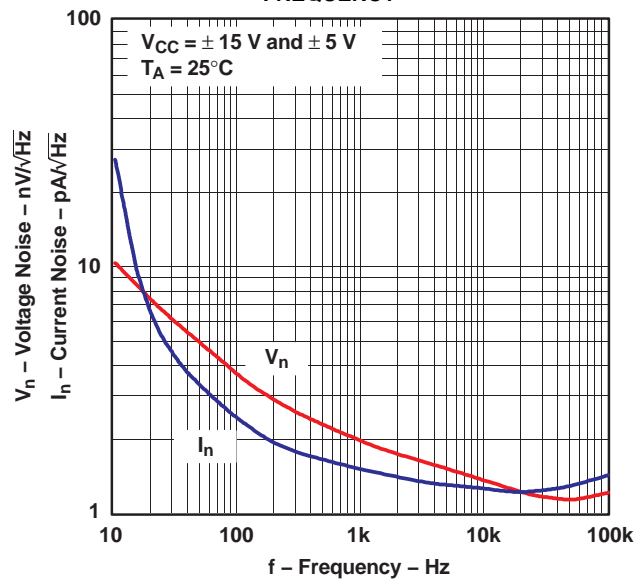
### DESCRIPTION

The THS4021 and THS4022 are ultralow voltage noise, high-speed voltage feedback amplifiers that are ideal for applications requiring low voltage noise, including communication and imaging. The single-amplifier THS4021 and the dual-amplifier THS4022 offer very good ac performance with 350-MHz bandwidth, 470-V/ $\mu\text{s}$  slew rate, and 40-ns settling time (0.1%). The THS4021 and THS4022 are stable at gains of 10 ( $-9$ ) or greater. These amplifiers have a high drive capability of 100 mA and draw only 7.8-mA supply current per channel. With total harmonic distortion (THD) of  $-68\text{ dBc}$  at  $f = 1\text{ MHz}$ , the THS4021 and THS4022 are ideally suited for applications requiring low distortion.



Cross Section View Showing PowerPAD Option (DGN)

### VOLTAGE AND CURRENT NOISE vs FREQUENCY



G001

Figure 1.

| RELATED DEVICES |                                              |
|-----------------|----------------------------------------------|
| DEVICE          | DESCRIPTION                                  |
| THS4011/4012    | 290-MHz Low-Distortion High-Speed Amplifiers |
| THS4031/4032    | 100-MHz Low-Noise High-Speed Amplifiers      |
| THS4061/4062    | 180-MHz High-Speed Amplifiers                |



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PRODUCTION DATA information is current as of publication date. Products conform to specifications per the terms of the Texas Instruments standard warranty. Production processing does not necessarily include testing of all parameters.



CAUTION: The THS4021 and THS4022 provide ESD protection circuitry. However, permanent damage can still occur if this device is subjected to high-energy electrostatic discharges. Proper ESD precautions are recommended to avoid any performance degradation or loss of functionality.

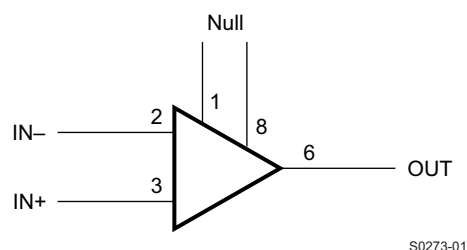
### AVAILABLE OPTIONS<sup>(1)</sup>

| $T_A$         | NUMBER OF CHANNELS | PACKAGED DEVICES                         |                                   | MSOP SYMBOL | EVALUATION MODULE |
|---------------|--------------------|------------------------------------------|-----------------------------------|-------------|-------------------|
|               |                    | PLASTIC SMALL OUTLINE <sup>(2)</sup> (D) | PLASTIC MSOP <sup>(2)</sup> (DGN) |             |                   |
| 0°C to 70°C   | 1                  | THS4021CD                                | THS4021CDGN                       | ACK         | THS4021EVM        |
|               | 2                  | THS4022CD                                | THS4022CDGN                       | ACA         | THS4022EVM        |
| –40°C to 85°C | 1                  | THS4021ID                                | THS4021CIDGN                      | ACL         | –                 |
|               | 2                  | THS4022ID                                | THS4022CIDGN                      | ACB         | –                 |

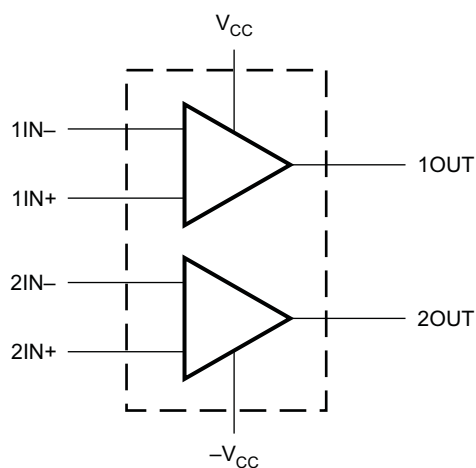
(1) For the most current package and ordering information, see the *Package Option Addendum* at the end of this document, or see the TI Web site at [www.ti.com](http://www.ti.com).

(2) The D and DGN packages are available taped and reeled. Add an R suffix to the device type (for example, THS4021CDGN).

### FUNCTIONAL BLOCK DIAGRAMS



**Figure 2. THS4021—Single Channel**



**Figure 3. THS4022—Dual Channel**

## ABSOLUTE MAXIMUM RATINGS<sup>(1)</sup>

over operating free-air temperature range (unless otherwise noted)

|           |                                                              | VALUE                         | UNIT |
|-----------|--------------------------------------------------------------|-------------------------------|------|
| $V_{CC}$  | Supply voltage                                               | $\pm 16.5$                    | V    |
| $V_I$     | Input voltage                                                | $\pm V_{CC}$                  | V    |
| $I_O$     | Output current                                               | 150                           | mA   |
| $V_{IO}$  | Differential input voltage                                   | $\pm 4$                       | V    |
|           | Continuous total power dissipation                           | See Dissipation Ratings table |      |
| $T_J$     | Maximum junction temperature                                 | 150                           | °C   |
| $T_A$     | Operating free-air temperature: C-suffix<br>I-suffix         | 0 to 70                       | °C   |
|           |                                                              | –40 to 85                     |      |
| $T_{stg}$ | Storage temperature                                          | –65 to 150                    | °C   |
|           | Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds | 300                           | °C   |

- (1) Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

## DISSIPATION RATINGS

| PACKAGE            | $\theta_{JA}$<br>(°C/W) | $\theta_{JC}$<br>(°C/W) | $T_A = 25^\circ\text{C}$<br>POWER RATING |
|--------------------|-------------------------|-------------------------|------------------------------------------|
| D <sup>(1)</sup>   | 167                     | 38.3                    | 740 mW                                   |
| DGN <sup>(2)</sup> | 58.4                    | 4.7                     | 2.14 W                                   |

- (1) This data was taken using the JEDEC standard low-K test PCB. For the JEDEC proposed high-K test PCB, the  $\theta_{JA}$  is 95°C/W with a power rating at  $T_A = 25^\circ\text{C}$  of 1.32 W.
- (2) This data was taken using 2-oz. (0.071-mm thick) trace and copper pad on a 3-in.  $\times$  3-in. (7.62-cm  $\times$  7.62-cm) PCB, with the device soldered directly to the board. For further information, see the [Application Information](#) section of this data sheet.

## RECOMMENDED OPERATING CONDITIONS

|                         |                                |               | MIN       | NOM | MAX      | UNIT |
|-------------------------|--------------------------------|---------------|-----------|-----|----------|------|
| $V_{CC+}$ and $V_{CC-}$ | Supply voltage                 | Dual supply   | $\pm 4.5$ |     | $\pm 16$ | V    |
|                         |                                | Single supply | 9         |     | 32       |      |
| $T_A$                   | Operating free-air temperature | C-suffix      | 0         |     | 70       | °C   |
|                         |                                | I-suffix      | –40       |     | 85       |      |

## ELECTRICAL CHARACTERISTICS

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = \pm 15\text{ V}$ ,  $R_L = 150\ \Omega$  (unless otherwise noted)

| PARAMETER           |                                     | TEST CONDITIONS                                    |           | MIN | TYP  | MAX  | UNIT |
|---------------------|-------------------------------------|----------------------------------------------------|-----------|-----|------|------|------|
| Dynamic Performance |                                     |                                                    |           |     |      |      |      |
| BW                  | Small-signal bandwidth<br>(−3 dB)   | V <sub>CC</sub> = ±15 V                            | Gain = 10 | 350 |      | MHz  |      |
|                     |                                     | V <sub>CC</sub> = ±5 V                             |           | 280 |      |      |      |
|                     |                                     | V <sub>CC</sub> = ±15 V                            | Gain = 20 | 80  |      |      |      |
|                     |                                     | V <sub>CC</sub> = ±5 V                             |           | 70  |      |      |      |
|                     | Bandwidth for 0 1-dB flatness       | V <sub>CC</sub> = ±15 V                            | Gain = 10 | 17  |      |      |      |
|                     |                                     | V <sub>CC</sub> = ±5 V                             |           | 17  |      |      |      |
|                     | Full power bandwidth <sup>(1)</sup> | V <sub>O(pp)</sub> = 20 V, V <sub>CC</sub> = ±15 V |           |     | 3.7  |      |      |
|                     |                                     | V <sub>O(pp)</sub> = 5 V, V <sub>CC</sub> = ±5 V   |           |     | 11.8 |      |      |
| SR                  | Slew rate <sup>(2)</sup>            | V <sub>CC</sub> = ±15 V, 10-V step                 | Gain = 10 | 470 |      | V/μs |      |
|                     |                                     | V <sub>CC</sub> = ±5 V, 5-V step                   |           | 370 |      |      |      |

- (1) Full-power bandwidth = slew rate /  $2\pi V_{O(Peak)}$ .

- (2) Slew rate is measured from an output level range of 25% to 75%.

## ELECTRICAL CHARACTERISTICS (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = \pm 15\text{ V}$ ,  $R_L = 150\ \Omega$  (unless otherwise noted)

| PARAMETER                    |                                             | TEST CONDITIONS                                                                |                             | MIN   | TYP   | MAX   | UNIT   |
|------------------------------|---------------------------------------------|--------------------------------------------------------------------------------|-----------------------------|-------|-------|-------|--------|
| t <sub>s</sub>               | Settling time to 0.1%                       | V <sub>CC</sub> = ±15 V, 5-V step                                              | Gain = −10                  |       | 40    |       | ns     |
|                              |                                             | V <sub>CC</sub> = ±5 V, 2-V step                                               |                             |       | 50    |       |        |
|                              | Settling time to 0.01%                      | V <sub>CC</sub> = ±15 V, 5-V step                                              | Gain = −10                  |       | 145   |       |        |
|                              |                                             | V <sub>CC</sub> = ±5 V, 2-V step                                               |                             |       | 150   |       |        |
| Noise/Distortion Performance |                                             |                                                                                |                             |       |       |       |        |
| THD                          | Total harmonic distortion                   | V <sub>O(pp)</sub> = 2 V, f = 1 MHz, gain = 2, V <sub>CC</sub> = ±15 V         | R <sub>L</sub> = 150 Ω      |       | −68   |       | dBc    |
|                              |                                             |                                                                                | R <sub>L</sub> = 1 kΩ       |       | −77   |       |        |
|                              |                                             | V <sub>O(pp)</sub> = 2 V, f = 1 MHz, gain = 2, V <sub>CC</sub> = ±5 V          | R <sub>L</sub> = 150 Ω      |       | −69   |       |        |
|                              |                                             |                                                                                | R <sub>L</sub> = 1 kΩ       |       | −78   |       |        |
| V <sub>n</sub>               | Input voltage noise                         | V <sub>CC</sub> = ±5 V or ±15 V, f > 10 kHz                                    |                             |       | 1.5   |       | nV/√Hz |
| I <sub>n</sub>               | Input current noise                         | V <sub>CC</sub> = ±5 V or ±15 V, f > 10 kHz                                    |                             |       | 2     |       | pA/√Hz |
| Differential gain error      |                                             | Gain = 2, NTSC, 40 IRE modulation, ±100 IRE ramp                               | V <sub>CC</sub> = ±15       |       | 0.02% |       |        |
|                              |                                             |                                                                                | V <sub>CC</sub> = ±5 V      |       | 0.02% |       |        |
| Differential phase error     |                                             | Gain = 2, NTSC, 40 IRE modulation, ±100 IRE ramp                               | V <sub>CC</sub> = ±15       |       | 0.08  |       | °      |
|                              |                                             |                                                                                | V <sub>CC</sub> = ±5 V      |       | 0.06  |       |        |
| X <sub>T</sub>               | Channel-to-channel crosstalk (THS4022 only) | V <sub>CC</sub> = ±5 V or ±15 V, f = 1 MHz                                     |                             |       | −60   |       | dB     |
| DC Performance               |                                             |                                                                                |                             |       |       |       |        |
| Open-loop gain               |                                             | V <sub>CC</sub> = ±15 V, V <sub>O</sub> = ±10 V, R <sub>L</sub> = 1 kΩ         | T <sub>A</sub> = 25°C       | 40    | 60    |       | V/mV   |
|                              |                                             |                                                                                | T <sub>A</sub> = full range | 35    |       |       |        |
|                              |                                             | V <sub>CC</sub> = ±5 V, V <sub>O</sub> = ±2.5 V, R <sub>L</sub> = 250 Ω        | T <sub>A</sub> = 25°C       | 20    | 35    |       |        |
|                              |                                             |                                                                                | T <sub>A</sub> = full range | 15    |       |       |        |
| V <sub>OS</sub>              | Input offset voltage                        | V <sub>CC</sub> = ±5 V or ±15 V                                                | T <sub>A</sub> = 25°C       |       | 0.5   | 2     | mV     |
|                              | T <sub>A</sub> = full range                 |                                                                                |                             |       | 3     |       |        |
| Offset voltage drift         | T <sub>A</sub> = full range                 |                                                                                |                             | 15    |       | μV/°C |        |
| I <sub>IB</sub>              | Input bias current                          |                                                                                | T <sub>A</sub> = 25°C       |       | 3     | 6     | μA     |
|                              | T <sub>A</sub> = full range                 |                                                                                |                             |       | 6     |       |        |
| I <sub>OS</sub>              | Input offset current                        |                                                                                | T <sub>A</sub> = 25°C       |       | 30    | 250   | nA     |
|                              | T <sub>A</sub> = full range                 |                                                                                |                             |       | 400   |       |        |
| Offset current drift         |                                             | T <sub>A</sub> = full range                                                    |                             |       | 0.3   |       | nA/°C  |
| Input Characteristics        |                                             |                                                                                |                             |       |       |       |        |
| V <sub>ICR</sub>             | Common-mode input voltage range             | V <sub>CC</sub> = ±15 V                                                        |                             | ±13.8 | ±14.3 |       | V      |
|                              |                                             | V <sub>CC</sub> = ±5 V                                                         |                             | ±3.8  | ±4.3  |       |        |
| CMRR                         | Common-mode rejection ratio                 | V <sub>CC</sub> = ±15 V, V <sub>ICR</sub> = ±12 V, T <sub>A</sub> = full range |                             | 74    | 95    |       | dB     |
| r <sub>i</sub>               | Input resistance                            |                                                                                |                             |       | 1     |       | MΩ     |
| C <sub>i</sub>               | Input capacitance                           |                                                                                |                             |       | 1.5   |       | pF     |
| Output Characteristics       |                                             |                                                                                |                             |       |       |       |        |
| V <sub>O</sub>               | Output voltage swing                        | V <sub>CC</sub> = ±15 V                                                        | R <sub>L</sub> = 250 Ω      | ±12   | ±12.5 |       | V      |
|                              |                                             | V <sub>CC</sub> = ±5 V                                                         | R <sub>L</sub> = 150 Ω      | ±3    | ±3.3  |       |        |
|                              |                                             | V <sub>CC</sub> = ±15 V                                                        | R <sub>L</sub> = 1 kΩ       | ±13   | ±13.5 |       |        |
|                              |                                             | V <sub>CC</sub> = ±5 V                                                         |                             | ±3.4  | ±3.8  |       |        |
| I <sub>O</sub>               | Output current                              | V <sub>CC</sub> = ±15 V                                                        | R <sub>L</sub> = 20 Ω       | 80    | 100   |       | mA     |
|                              |                                             | V <sub>CC</sub> = ±5 V                                                         |                             | 50    | 75    |       |        |
| I <sub>SC</sub>              | Short-circuit current <sup>(3)</sup>        | V <sub>CC</sub> = ±15 V                                                        |                             |       | 150   |       | mA     |
| R <sub>O</sub>               | Output resistance <sup>(3)</sup>            | Open loop                                                                      |                             |       | 13    |       | Ω      |

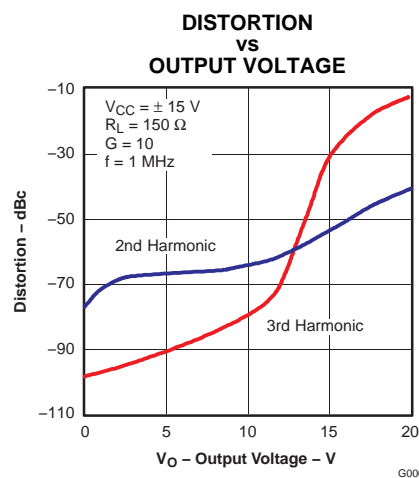
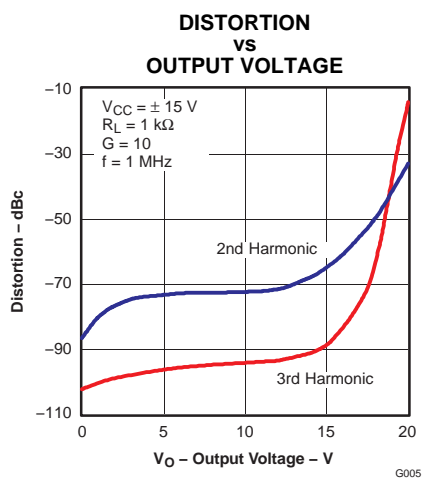
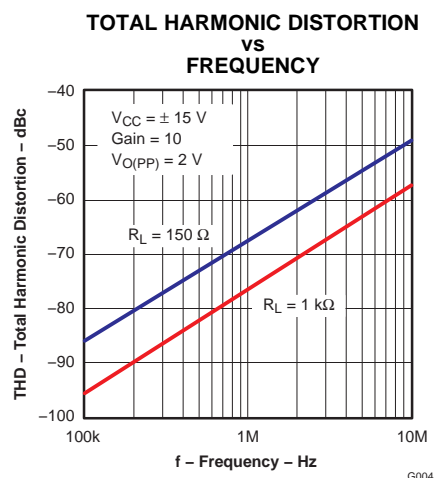
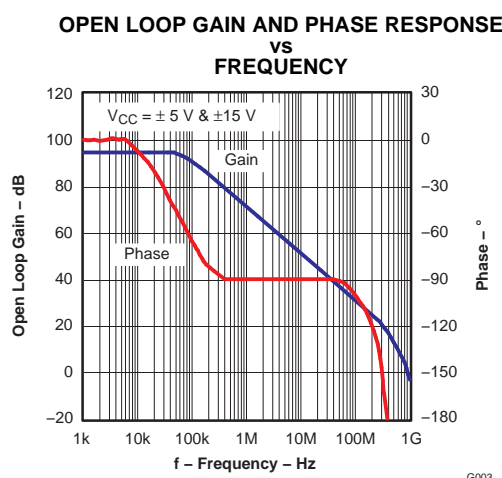
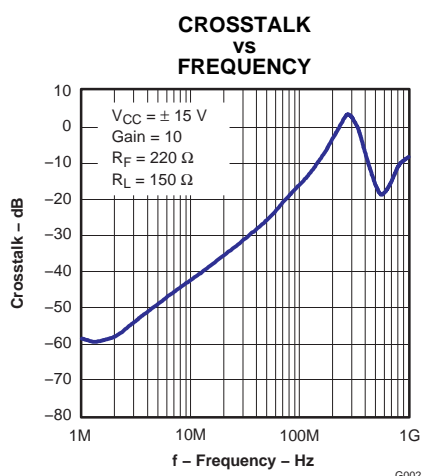
(3) Observe power dissipation ratings to keep the junction temperature below the absolute maximum rating when the output is heavily loaded or shorted. See the [Absolute Maximum Ratings](#) table of this data sheet for more information.

## ELECTRICAL CHARACTERISTICS (continued)

at  $T_A = 25^\circ\text{C}$ ,  $V_{CC} = \pm 15\text{ V}$ ,  $R_L = 150\ \Omega$  (unless otherwise noted)

| PARAMETER           |                                | TEST CONDITIONS                                                            | MIN       | TYP                       | MAX        | UNIT |
|---------------------|--------------------------------|----------------------------------------------------------------------------|-----------|---------------------------|------------|------|
| <b>Power Supply</b> |                                |                                                                            |           |                           |            |      |
| $V_{CC}$            | Supply voltage operating range | Dual supply                                                                | $\pm 4.5$ |                           | $\pm 16.5$ | V    |
|                     |                                | Single supply                                                              | 9         |                           | 33         |      |
| $I_{CC}$            | Supply current (per amplifier) | $V_{CC} = \pm 15\text{ V}$                                                 |           | $T_A = 25^\circ\text{C}$  | 7.8        | mA   |
|                     |                                |                                                                            |           | $T_A = \text{full range}$ | 11         |      |
|                     |                                | $V_{CC} = \pm 5\text{ V}$                                                  |           | $T_A = 25^\circ\text{C}$  | 6.7        |      |
|                     |                                |                                                                            |           | $T_A = \text{full range}$ | 10.5       |      |
| PSRR                | Power-supply rejection ratio   | $V_{CC} = \pm 5\text{ V}$ or $\pm 15\text{ V}$ , $T_A = \text{full range}$ | 80        | 95                        |            | dB   |

## TYPICAL CHARACTERISTICS



## TYPICAL CHARACTERISTICS (continued)

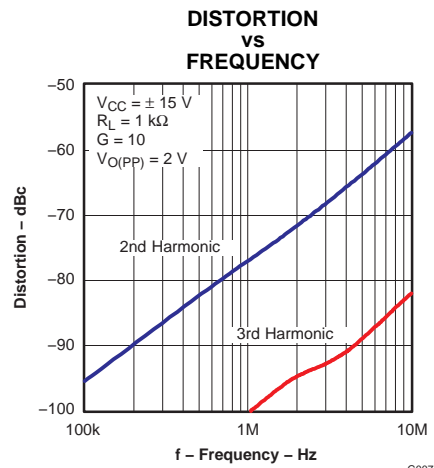


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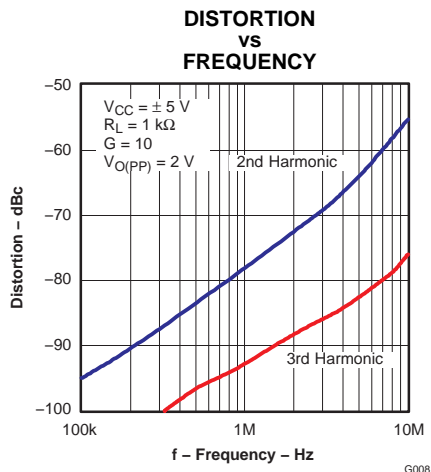


Figure 10.

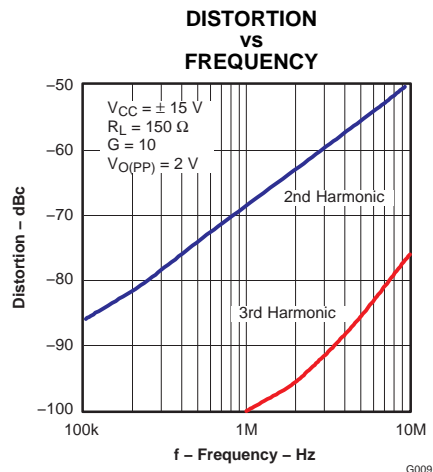


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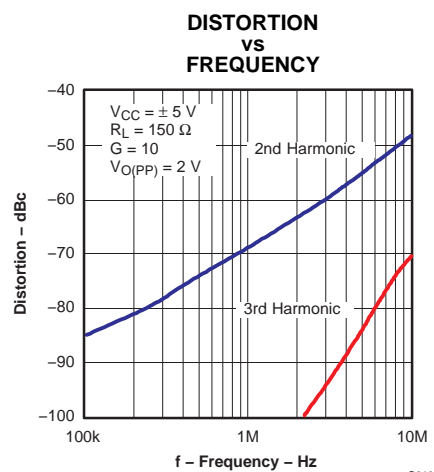


Figure 12.

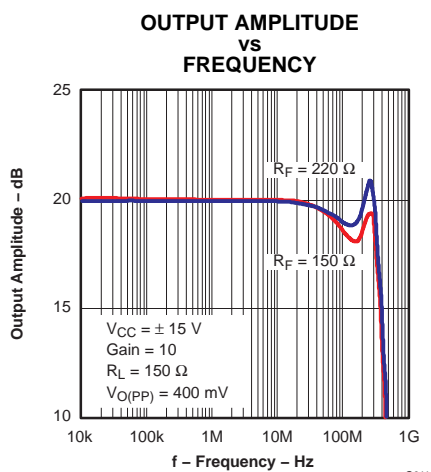


Figure 13.

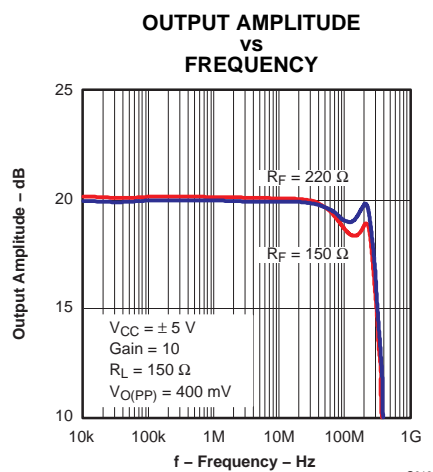


Figure 14.

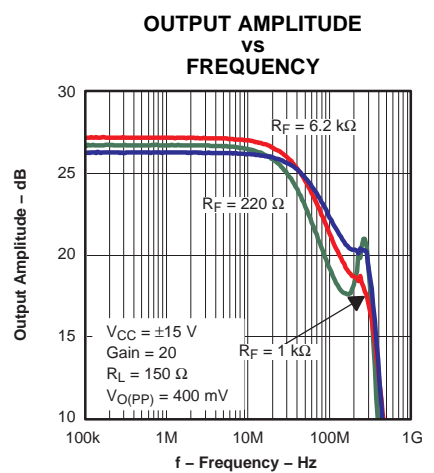


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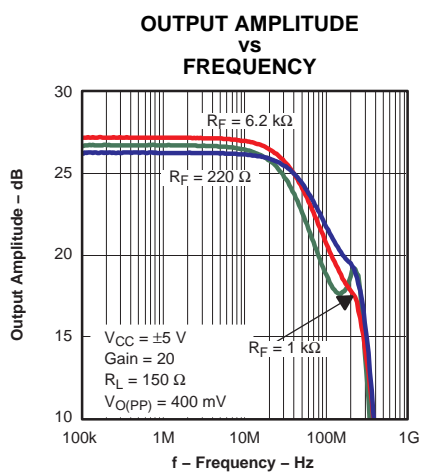


Figure 16.

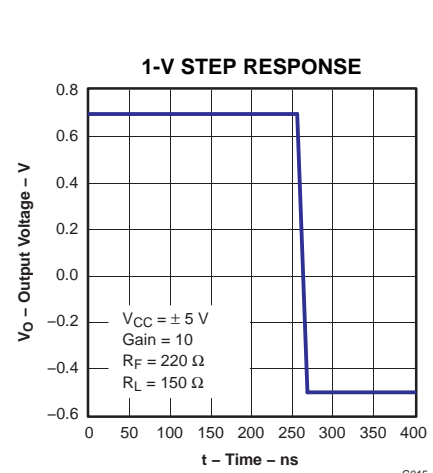


Figure 17.

## TYPICAL CHARACTERISTICS (continued)

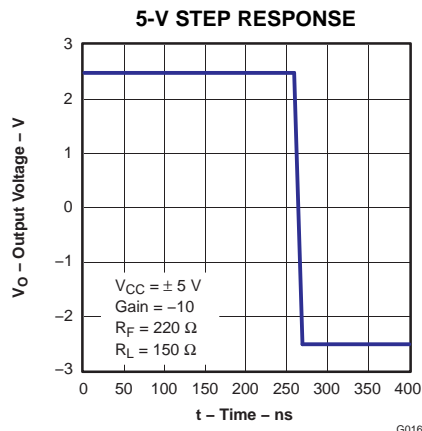


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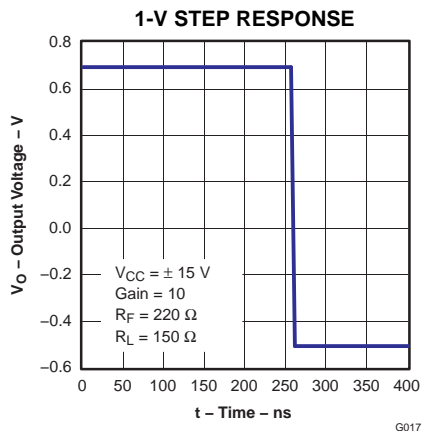


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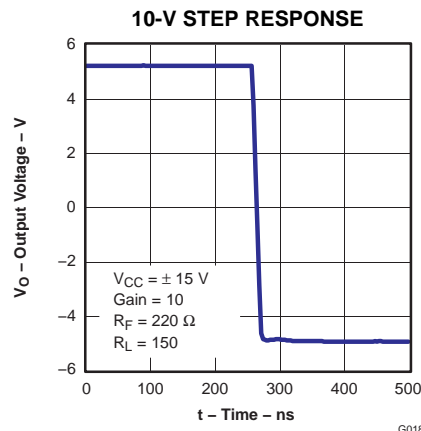


Figure 20.

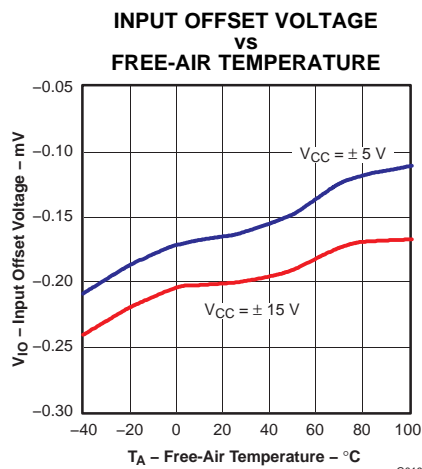


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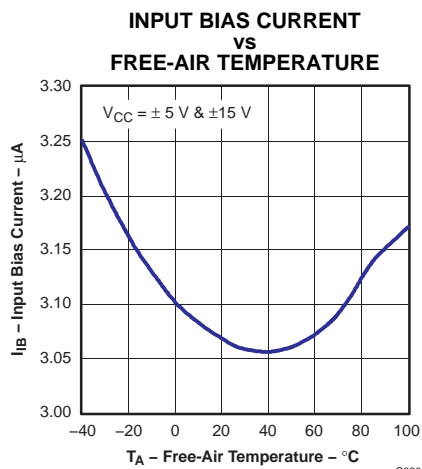


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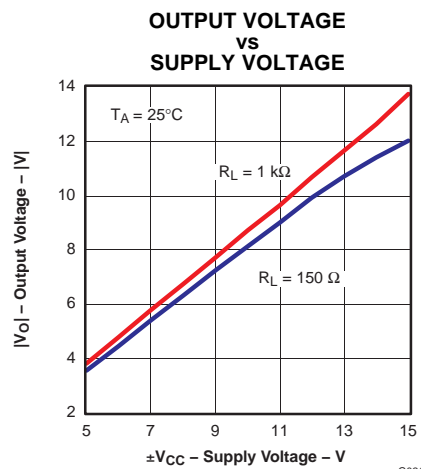


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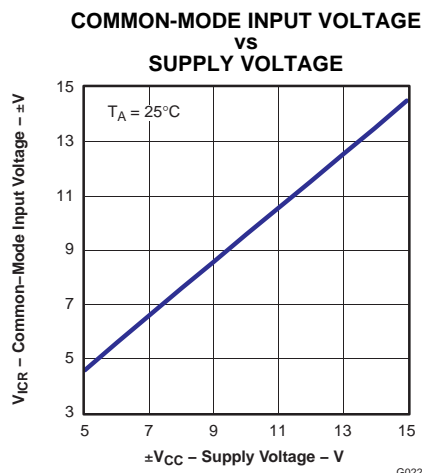


Figure 24.

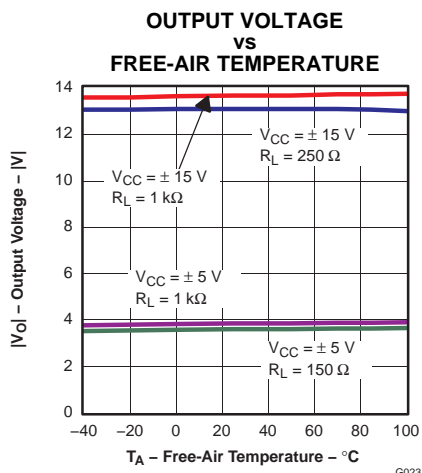


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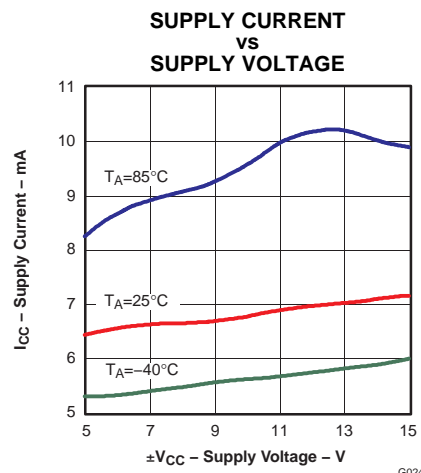


Figure 26.

## TYPICAL CHARACTERISTICS (continued)

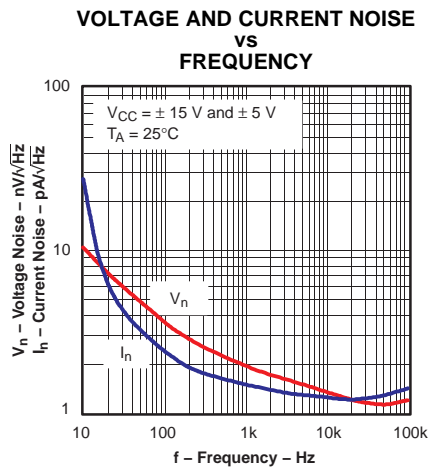


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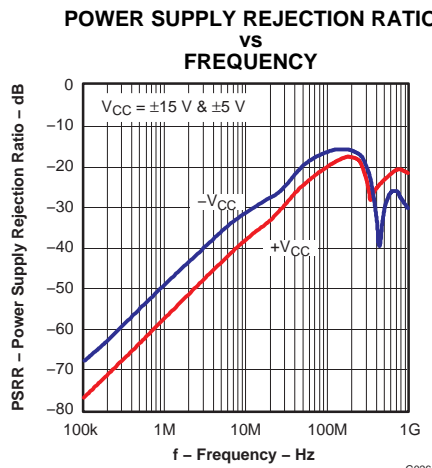


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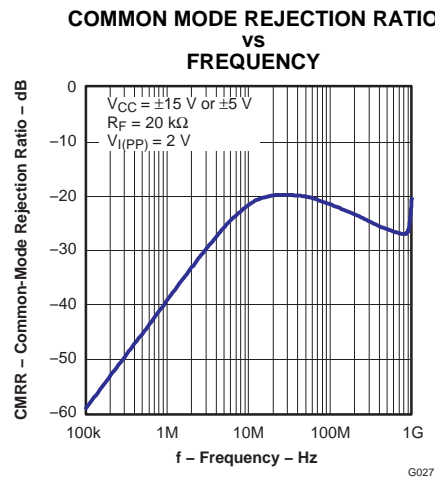


Figure 29.



## APPLICATION INFORMATION

### Theory of Operation

The THS402x is a high-speed operational amplifier configured in a voltage feedback architecture. It is built using a 30-V, dielectrically isolated, complementary bipolar process with NPN and PNP transistors possessing  $f_T$  of several GHz. This results in an exceptionally high-performance amplifier that has a wide bandwidth, high slew rate, fast settling time, and low distortion. A simplified schematic is shown in Figure 30.

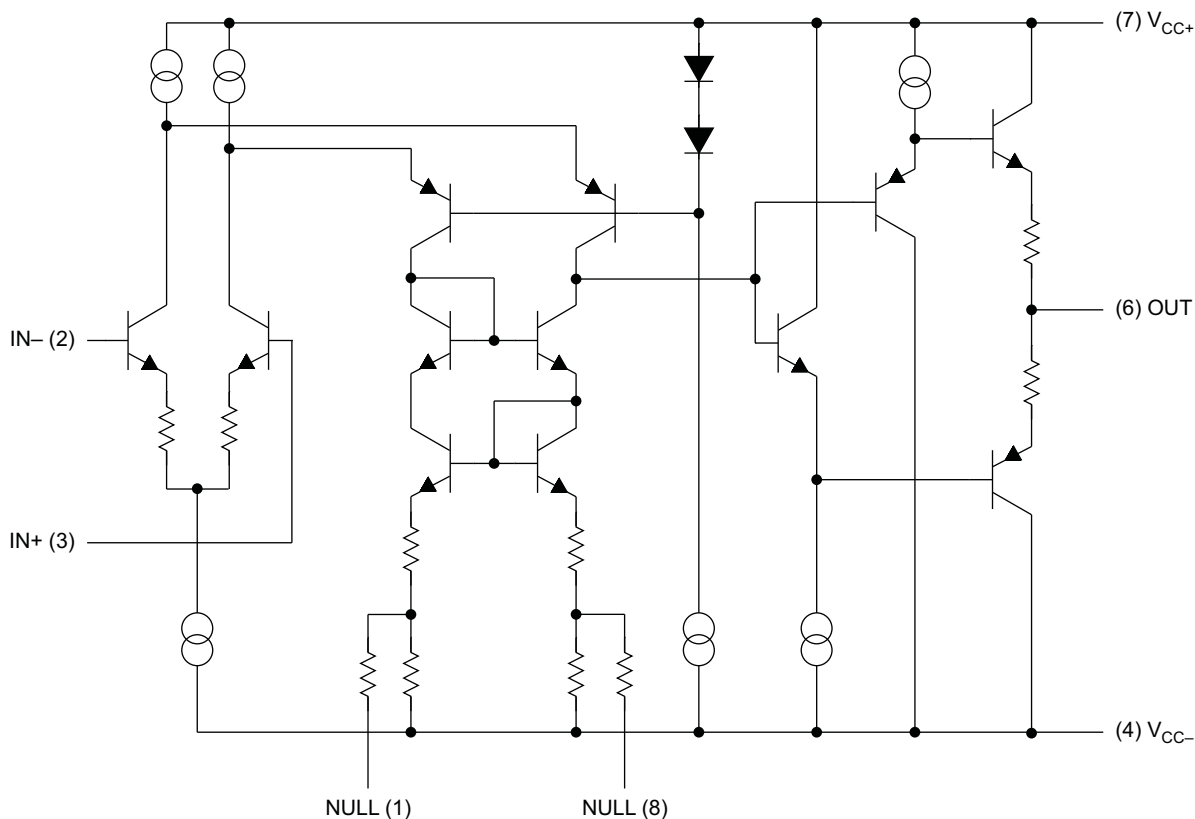
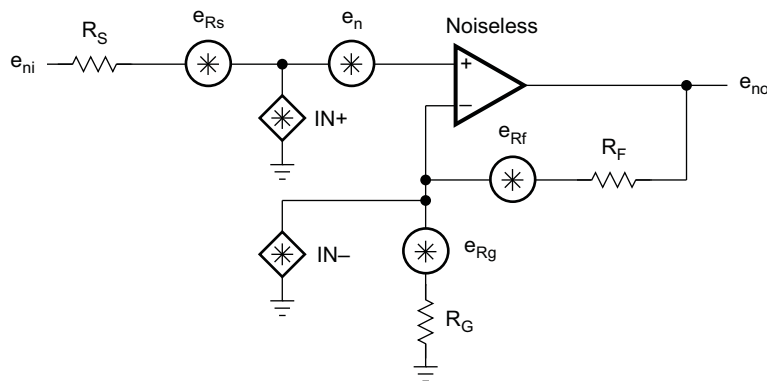


Figure 30. THS4021 Simplified Schematic

### Noise Calculations and Noise Figure

Noise can cause errors on very small signals. This is especially true when amplifying small signals, where signal-to-noise ratio (SNR) is very important. The noise model for the THS402x is shown in Figure 31. This model includes all of the noise sources as follows:

- $e_n$  = Amplifier internal voltage noise ( $\text{nV}/\sqrt{\text{Hz}}$ )
- $IN+$  = Noninverting current noise ( $\text{pA}/\sqrt{\text{Hz}}$ )
- $IN-$  = Inverting current noise ( $\text{pA}/\sqrt{\text{Hz}}$ )
- $e_{RX}$  = Thermal voltage noise associated with each resistor ( $e_{RX} = 4 \text{ kTR}_X$ )



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**Figure 31. Noise Model**

The total equivalent input noise density ( $e_{ni}$ ) is calculated by using the following equation:

$$e_{ni} = \sqrt{(e_n)^2 + (IN+ \times R_S)^2 + (IN- \times (R_F \parallel R_G))^2 + 4kTR_S + 4kT(R_F \parallel R_G)}$$

where:

$k$  = Boltzmann's constant =  $1.380658 \times 10^{-23}$

$T$  = Temperature in degrees Kelvin ( $273 + ^\circ\text{C}$ )

$R_F \parallel R_G$  = Parallel resistance of  $R_F$  and  $R_G$

To get the equivalent output noise of the amplifier, just multiply the equivalent input noise density ( $e_{ni}$ ) by the overall amplifier gain ( $A_V$ ).

$$e_{no} = e_{ni} A_V = e_{ni} \left( 1 + \frac{R_F}{R_G} \right) \text{ (noninverting case)}$$

As the previous equations show, to keep noise at a minimum, small value resistors should be used. As the closed-loop gain is increased (by reducing  $R_G$ ), the input noise is reduced considerably because of the parallel resistance term. This leads to the general conclusion that the most dominant noise sources are the source resistor ( $R_S$ ) and the internal amplifier noise voltage ( $e_n$ ). Because noise is summed in a root-mean-squares method, noise sources smaller than 25% of the largest noise source can be effectively ignored. This can greatly simplify the formula and make noise calculations much easier to calculate.

For more information on noise analysis, see the *Noise Analysis in Operational Amplifier Circuits* application report (SLVA043).

This brings up another noise measurement usually preferred in RF applications, the noise figure (NF). Noise figure is a measure of noise degradation caused by the amplifier. The value of the source resistance must be defined and is typically  $50 \Omega$  in RF applications.

$$NF = 10 \log \left[ \frac{e_{ni}^2}{(e_{Rs})^2} \right]$$

Because the dominant noise components are generally the source resistance and the internal amplifier noise voltage, we can approximate noise figure as:

$$NF = 10 \log \left[ 1 + \frac{\left( e_n \right)^2 + \left( I_{N+} \times R_S \right)^2}{4 k T R_S} \right]$$

Figure 32 shows the noise figure graph for the THS402x.

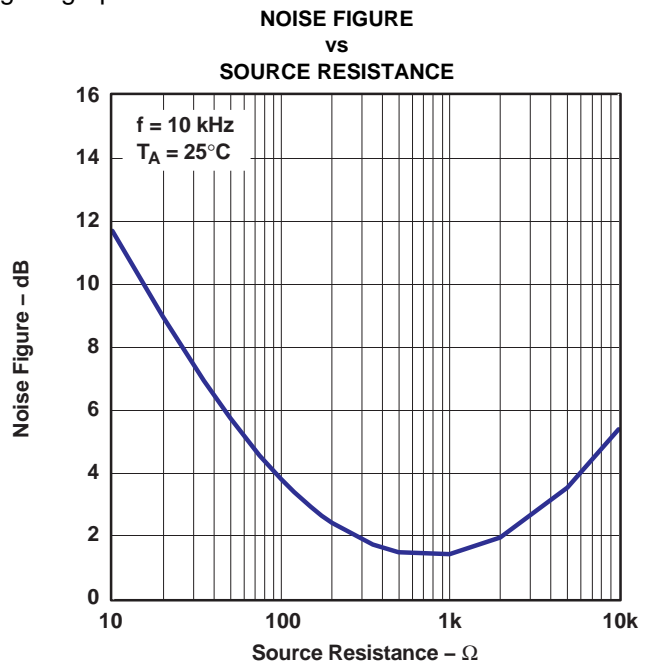


Figure 32. Noise Figure vs Source Resistance

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## Driving a Capacitive Load

Driving capacitive loads with high-performance amplifiers is not a problem as long as certain precautions are taken. The first is to realize that the THS402x has been internally compensated to maximize its bandwidth and slew-rate performance. When the amplifier is compensated in this manner, capacitive loading directly on the output decreases the device phase margin, leading to high-frequency ringing or oscillations. Therefore, for capacitive loads of greater than 10 pF, it is recommended that a resistor be placed in series with the output of the amplifier, as shown in [Figure 33](#). A minimum value of 20  $\Omega$  should work well for most applications. For example, in 75- $\Omega$  transmission systems, setting the series resistor value to 75  $\Omega$  both isolates any capacitance loading and provides the proper line impedance matching at the source end.

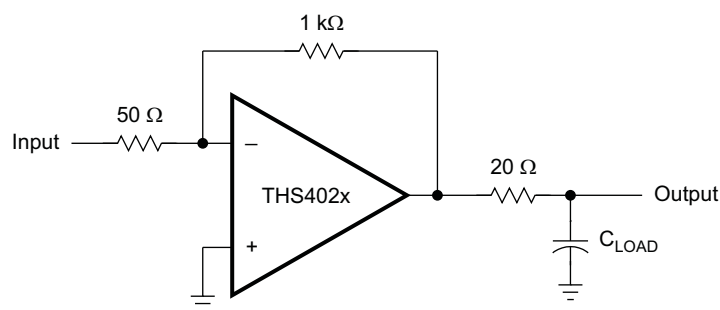


Figure 33. Driving a Capacitive Load

## Offset Nulling

The THS402x has very low input offset voltage for a high-speed amplifier. However, if additional correction is required, an offset nulling function has been provided on the THS4021. The input offset can be adjusted by placing a potentiometer between terminals 1 and 8 of the device and tying the wiper to the negative supply. This is shown in [Figure 34](#).

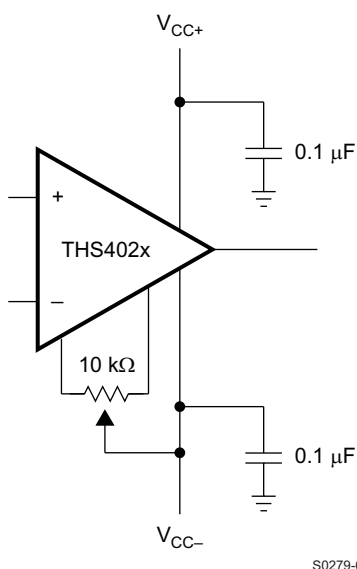
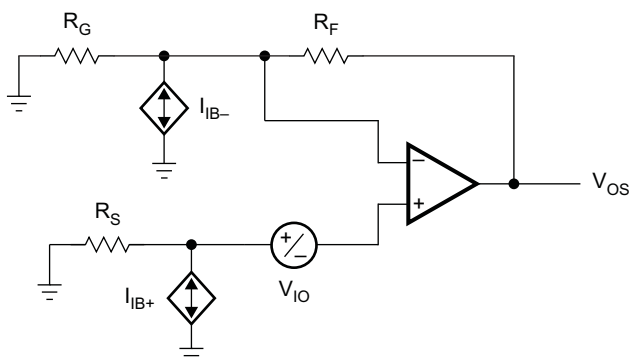


Figure 34. Offset Nulling Schematic

## Offset Voltage

The output offset voltage ( $V_{OO}$ ) is the sum of the input offset voltage ( $V_{IO}$ ) and both input bias currents ( $I_{IB}$ ) times the corresponding gains. The schematic and formula of Figure 35 can be used to calculate the output offset voltage.



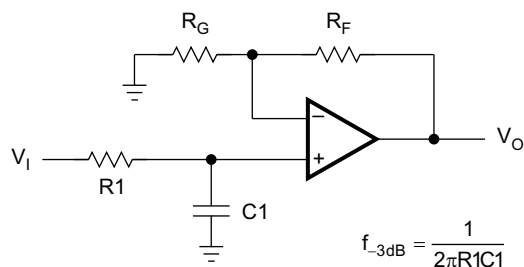
$$V_{OS} = (\pm V_{IO} \pm I_{IB+} \times R_S) \left( 1 + \frac{R_F}{R_G} \right) \pm I_{IB-} \times R_F$$

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Figure 35. Output Offset Voltage Model

## General Configurations

When receiving low-level signals, limiting the bandwidth of the incoming signals into the system is often required. The simplest way to accomplish this is to place an RC filter at the noninverting terminal of the amplifier (see Figure 36).



$$f_{-3dB} = \frac{1}{2\pi R1 C1}$$

$$\frac{V_O}{V_I} = \left( 1 + \frac{R_F}{R_G} \right) \left( \frac{1}{1 + sR1C1} \right)$$

S0281-01

Figure 36. Single-Pole Low-Pass Filter

## Circuit Layout Considerations

To achieve the levels of high-frequency performance of the THS402x, follow proper printed-circuit board high-frequency design techniques. A general set of guidelines is given as follows. In addition, a THS402x evaluation board is available to use as a guide for layout or for evaluating the device performance.

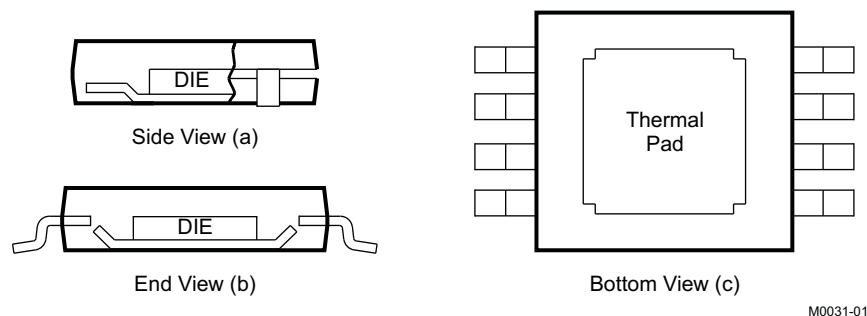
- **Ground planes**—It is highly recommended that a ground plane be used on the board to provide all components with a low-inductance ground connection. However, in the areas of the amplifier inputs and output, the ground plane can be removed to minimize the stray capacitance.
- **Proper power-supply decoupling**—Use a 6.8- $\mu$ F tantalum capacitor in parallel with a 0.1- $\mu$ F ceramic capacitor on each supply terminal. It may be possible to share the tantalum among several amplifiers depending on the application, but a 0.1- $\mu$ F ceramic capacitor should always be used on the supply terminal of every amplifier. In addition, the 0.1- $\mu$ F capacitor should be placed as close as possible to the supply terminal. As this distance increases, the inductance in the connecting trace makes the capacitor less effective. The designer should strive for distances of less than 0.1 inch (2.54 mm) between the device power terminals and the ceramic capacitors.
- **Sockets**—Sockets are not recommended for high-speed operational amplifiers. The additional lead inductance in the socket pins often produces stability problems. Surface-mount packages soldered directly to the PCB is the best implementation.
- **Short trace runs/compact part placements**—Optimum high-frequency performance is achieved when stray series inductance has been minimized. To realize this, the circuit layout should be made as compact as possible, thereby minimizing the length of all trace runs. Particular attention should be paid to the inverting input of the amplifier. Its length should be kept as short as possible. This helps to minimize stray capacitance at the input of the amplifier.
- **Surface-mount passive components**—Using surface-mount passive components is recommended for high-frequency amplifier circuits for several reasons. First, because of the extremely low lead inductance of surface-mount components, the problem with stray series inductance is greatly reduced. Second, the small size of surface-mount components naturally leads to a more compact layout, thereby minimizing both stray inductance and capacitance. If leaded components are used, it is recommended that the lead lengths be kept as short as possible.

## General Thermal Pad Design Considerations

The THS402x is available packaged in a thermally-enhanced DGN package, which is a member of the PowerPAD family of packages. This package is constructed using a downset leadframe upon which the die is mounted [see Figure 37(a) and Figure 37(b)]. This arrangement results in the lead frame being exposed as a thermal pad on the underside of the package [see Figure 37(c)]. Because this thermal pad has direct thermal contact with the die, excellent thermal performance can be achieved by providing a good thermal path away from the thermal pad.

The PowerPAD package allows for both assembly and thermal management in one manufacturing operation. During the surface-mount solder operation (when the leads are being soldered), the thermal pad can also be soldered to a copper area underneath the package. Through the use of thermal paths within this copper area, heat can be conducted away from the package into either a ground plane or other heat dissipating device.

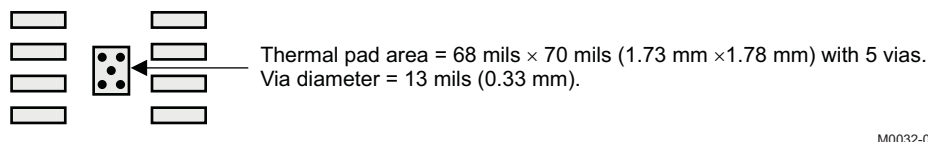
The PowerPAD package represents a design breakthrough, combining the small area and ease of the surface mount assembly method to eliminate the previously difficult mechanical methods of heatsinking.



NOTE: The thermal pad is electrically isolated from all terminals in the package.

**Figure 37. Views of Thermally Enhanced DGN Package**

Although there are many ways to heatsink this device properly, the following steps illustrate the recommended approach.



**Figure 38. Thermal Pad PCB Etch and Via Pattern**

1. Prepare the PCB with a top side etch pattern as shown in Figure 38. There should be etch for the leads as well as etch for the thermal pad.
2. Place five holes in the area of the thermal pad. These holes should be 13 mils (0.33 mm) in diameter. Keep them small so that solder wicking through the holes is not a problem during reflow.
3. Additional vias may be placed anywhere along the thermal plane outside of the thermal pad area. These vias help dissipate the heat generated by the THS402xDGN IC. These additional vias may be larger than the 13-mil (0.33-mm) diameter vias directly under the thermal pad. They can be larger because they are not in the thermal pad area to be soldered, so wicking is not a problem.
4. Connect all holes to the internal ground plane.
5. When connecting these holes to the ground plane, do not use the typical web or spoke via connection methodology. Web connections have a high thermal resistance connection that is useful for slowing the heat transfer during soldering operations. This makes the soldering of vias that have plane connections easier. In this application, however, low thermal resistance is desired for the most efficient heat transfer. Therefore, the holes under the THS402xDGN package should connect to the internal ground plane with a complete connection around the entire circumference of the plated-through hole.
6. The top-side solder mask should leave the terminals of the package and the thermal pad area with its five holes exposed. The bottom-side solder mask should cover the five holes of the thermal pad area. This prevents solder from being pulled away from the thermal pad area during the reflow process.

7. Apply solder paste to the exposed thermal pad area and all of the IC terminals.
8. With these preparatory steps in place, the THS402xDGN IC is simply placed in position and run through the solder reflow operation as any standard surface-mount component. This results in a part that is properly installed.

The actual thermal performance achieved with the THS402xDGN in its PowerPAD package depends on the application. In the example above, if the size of the internal ground plane is approximately 3 inches × 3 inches (7.62 cm × 7.62 cm), then the expected thermal coefficient,  $\theta_{JA}$ , is about 58.4°C/W. For comparison, the non-PowerPAD version of the THS402x IC (SOIC) is shown. For a given  $\theta_{JA}$ , the maximum power dissipation is shown in Figure 39 and is calculated by the following formula:

$$P_D = \left( \frac{T_{MAX} - T_A}{\theta_{JA}} \right)$$

where:

$P_D$  = Maximum power dissipation of THS402x IC (watts)

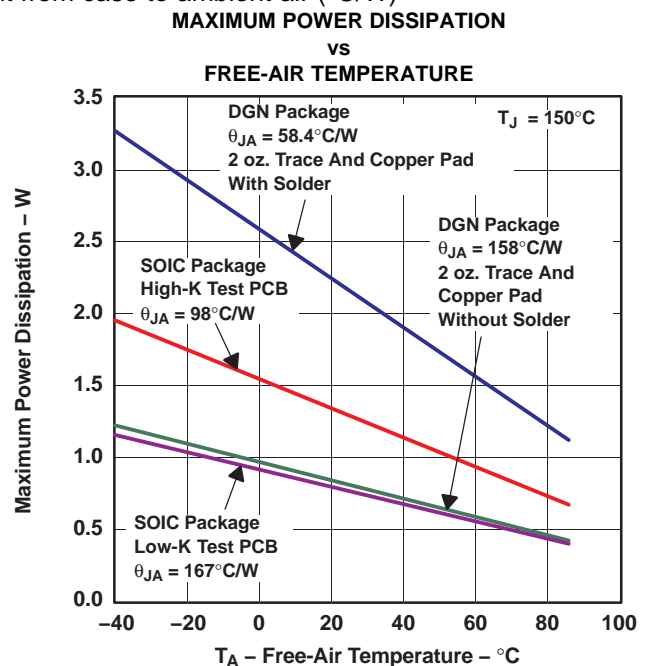
$T_{MAX}$  = Absolute maximum junction temperature (150°C)

$T_A$  = Free-ambient air temperature (°C)

$\theta_{JA} = \theta_{JC} + \theta_{CA}$

$\theta_{JC}$  = Thermal coefficient from junction to case

$\theta_{CA}$  = Thermal coefficient from case to ambient air (°C/W)



NOTE: Results are with no air flow and PCB size = 3 in. × 3 in. (7.62 cm × 7.62 cm).

**Figure 39. Maximum Power Dissipation vs Free-Air Temperature**

More-complete details of the thermal pad installation process and thermal management techniques can be found in the *PowerPAD Thermally Enhanced Package* application report ([SLMA002](#)).



The next consideration is the package constraints. The two sources of heat within an amplifier are quiescent power and output power. The designer should never forget about the quiescent heat generated within the device, especially with multi-amplifier devices. Because these devices have linear output stages (Class A-B), most of the heat dissipation is at low output voltages with high output currents. Figure 40 through Figure 43 show this effect, along with the quiescent heat, with an ambient air temperature of 50°C. Obviously, as the ambient temperature increases, the limit lines shown drop accordingly. The area under each respective limit line is considered the safe operating area. Any condition above this line exceeds the amplifier limits and failure may result. When using  $V_{CC} = \pm 5\text{ V}$ , there is generally not a heat problem, even with SOIC packages. But, when using  $V_{CC} = \pm 15\text{ V}$ , the SOIC package is severely limited in the amount of heat it can dissipate. The other key factor when looking at these graphs is how the devices are mounted on the PCB. The PowerPAD devices are extremely useful for heat dissipation. But the device should always be soldered to a copper plane to use fully the heat dissipation properties of the thermal pad. The SOIC package, on the other hand, is highly dependent on how it is mounted on the PCB. As more trace and copper area is placed around the device,  $\theta_{JA}$  decreases and the heat dissipation capability increases. The currents and voltages shown in these graphs are for the total package. For the dual-amplifier package (THS4022), the sum of the RMS output currents and voltages should be used to choose the proper package. The graphs shown assume that both amplifier outputs are identical.

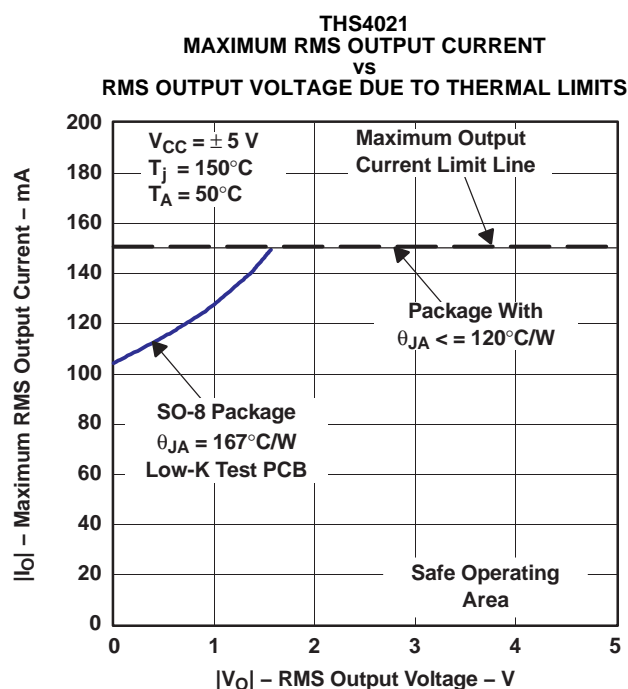


Figure 40.

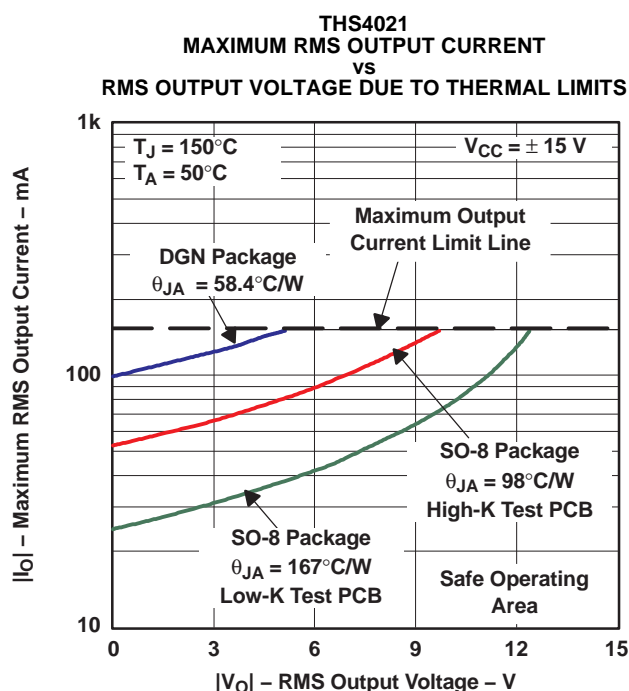


Figure 41.

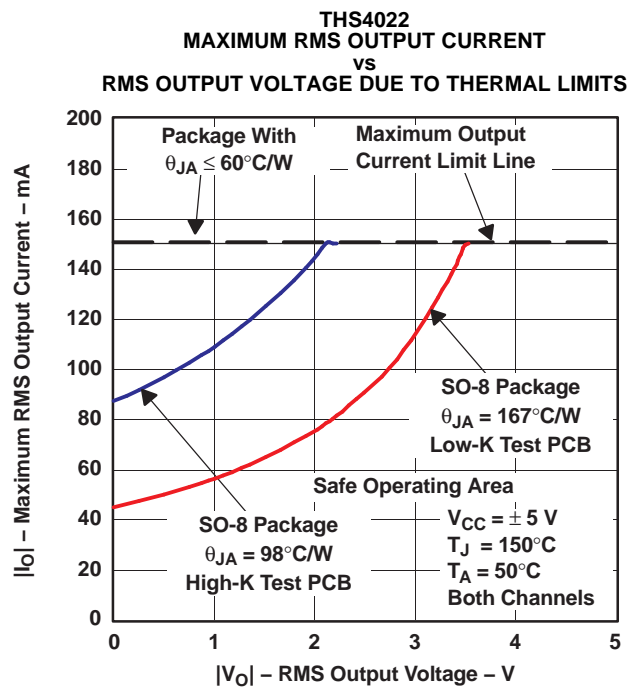


Figure 42.

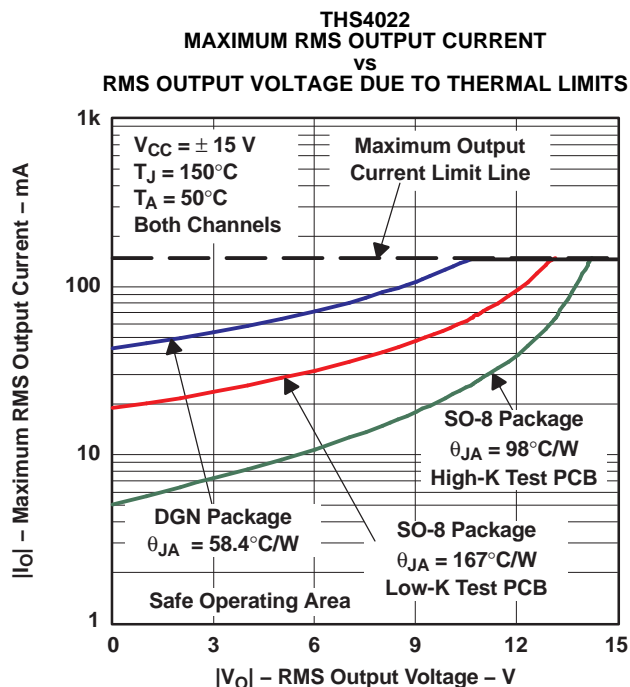
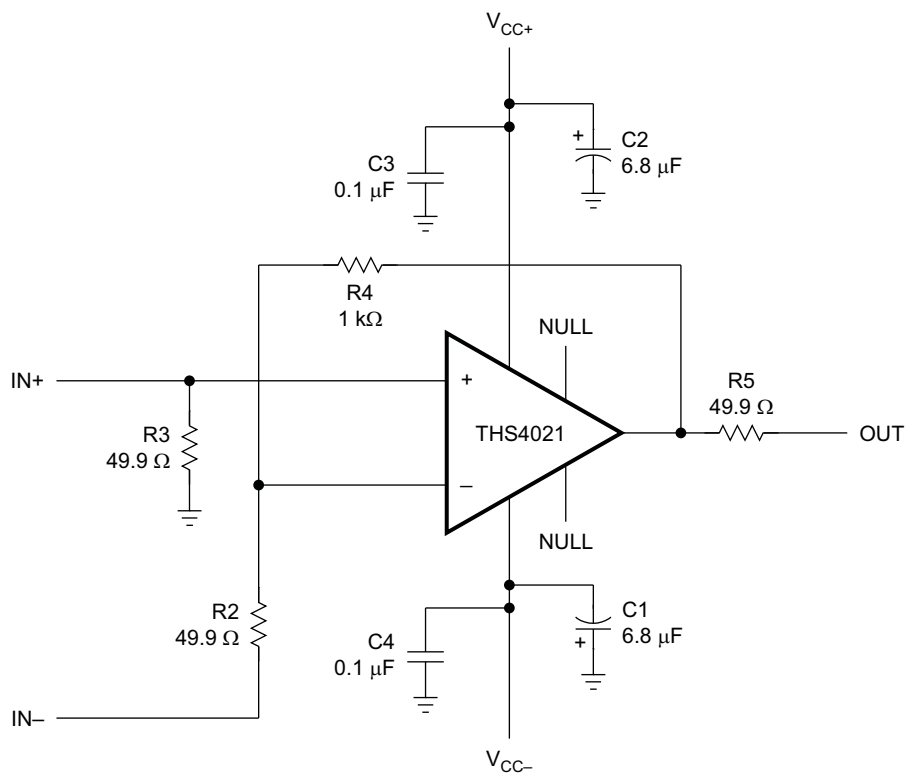


Figure 43.

## Evaluation Board

Evaluation boards are available for the THS4021 (literature number [SLOP129](#)) and THS4022 (literature number [SLOP231](#)). These boards have been configured for very low parasitic capacitance in order to realize the full performance of the amplifier. A schematic of the THS4021 evaluation board is shown in [Figure 44](#). The circuitry has been designed so that the amplifier may be used in either an inverting or noninverting configuration. For more information, see the *THS4021 High-Speed Operational Amplifier Evaluation Module* user's guide ([SLOU063](#)) or the *THS4022 Dual High-Speed Operational Amplifier Evaluation Module* user's guide ([SLOU064](#)). To order the evaluation board, contact your local TI sales office or distributor or visit the Texas Instruments Web site at [www.ti.com](http://www.ti.com).



S0282-01

**Figure 44. THS4021 Evaluation Board**

**PACKAGING INFORMATION**

| Orderable Device | Status<br>(1) | Package Type      | Package<br>Drawing | Pins | Package<br>Qty | Eco Plan<br>(2)            | Lead/Ball Finish<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|------------------|---------------|-------------------|--------------------|------|----------------|----------------------------|-------------------------|----------------------|--------------|-------------------------|-------------------------|
| THS4021CD        | ACTIVE        | SOIC              | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | 0 to 70      | 4021C                   | <a href="#">Samples</a> |
| THS4021CDG4      | ACTIVE        | SOIC              | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | 0 to 70      | 4021C                   | <a href="#">Samples</a> |
| THS4021CDGN      | ACTIVE        | MSOP-<br>PowerPAD | DGN                | 8    | 80             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | 0 to 70      | ACK                     | <a href="#">Samples</a> |
| THS4021CDGNG4    | ACTIVE        | MSOP-<br>PowerPAD | DGN                | 8    | 80             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | 0 to 70      | ACK                     | <a href="#">Samples</a> |
| THS4021CDGNR     | ACTIVE        | MSOP-<br>PowerPAD | DGN                | 8    | 2500           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | 0 to 70      | ACK                     | <a href="#">Samples</a> |
| THS4021ID        | ACTIVE        | SOIC              | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | -40 to 85    | 4021I                   | <a href="#">Samples</a> |
| THS4021IDG4      | ACTIVE        | SOIC              | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | -40 to 85    | 4021I                   | <a href="#">Samples</a> |
| THS4021IDGN      | ACTIVE        | MSOP-<br>PowerPAD | DGN                | 8    | 80             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | -40 to 85    | ACL                     | <a href="#">Samples</a> |
| THS4021IDGNR     | ACTIVE        | MSOP-<br>PowerPAD | DGN                | 8    | 2500           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | -40 to 85    | ACL                     | <a href="#">Samples</a> |
| THS4021IDR       | ACTIVE        | SOIC              | D                  | 8    | 2500           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | -40 to 85    | 4021I                   | <a href="#">Samples</a> |
| THS4022CD        | ACTIVE        | SOIC              | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | 0 to 70      | 4022C                   | <a href="#">Samples</a> |
| THS4022CDGN      | ACTIVE        | MSOP-<br>PowerPAD | DGN                | 8    | 80             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | 0 to 70      | ACA                     | <a href="#">Samples</a> |
| THS4022CDGNG4    | ACTIVE        | MSOP-<br>PowerPAD | DGN                | 8    | 80             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | 0 to 70      | ACA                     | <a href="#">Samples</a> |
| THS4022CDGNR     | ACTIVE        | MSOP-<br>PowerPAD | DGN                | 8    | 2500           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | 0 to 70      | ACA                     | <a href="#">Samples</a> |
| THS4022ID        | ACTIVE        | SOIC              | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | -40 to 85    | 4022I                   | <a href="#">Samples</a> |
| THS4022IDG4      | ACTIVE        | SOIC              | D                  | 8    | 75             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU               | Level-1-260C-UNLIM   | -40 to 85    | 4022I                   | <a href="#">Samples</a> |
| THS4022IDGN      | ACTIVE        | MSOP-<br>PowerPAD | DGN                | 8    | 80             | Green (RoHS<br>& no Sb/Br) | CU NIPDAU   Call TI     | Level-1-260C-UNLIM   | -40 to 85    | ACB                     | <a href="#">Samples</a> |

| Orderable Device | Status<br>(1) | Package Type      | Package<br>Drawing | Pins | Package<br>Qty | Eco Plan<br>(2)            | Lead/Ball Finish<br>(6) | MSL Peak Temp<br>(3) | Op Temp (°C) | Device Marking<br>(4/5) | Samples                 |
|------------------|---------------|-------------------|--------------------|------|----------------|----------------------------|-------------------------|----------------------|--------------|-------------------------|-------------------------|
| THS4022IDGNR     | ACTIVE        | MSOP-<br>PowerPAD | DGN                | 8    | 2500           | Green (RoHS<br>& no Sb/Br) | CU NIPDAU   Call TI     | Level-1-260C-UNLIM   | -40 to 85    | ACB                     | <a href="#">Samples</a> |

(1) The marketing status values are defined as follows:

**ACTIVE:** Product device recommended for new designs.

**LIFEBUY:** TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

**NRND:** Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

**PREVIEW:** Device has been announced but is not in production. Samples may or may not be available.

**OBSOLETE:** TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check <http://www.ti.com/productcontent> for the latest availability information and additional product content details.

**TBD:** The Pb-Free/Green conversion plan has not been defined.

**Pb-Free (RoHS):** TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.

**Pb-Free (RoHS Exempt):** This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.

**Green (RoHS & no Sb/Br):** TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

(6) Lead/Ball Finish - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead/Ball Finish values may wrap to two lines if the finish value exceeds the maximum column width.

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**TAPE AND REEL INFORMATION**


\*All dimensions are nominal

| Device       | Package Type   | Package Drawing | Pins | SPQ  | Reel Diameter (mm) | Reel Width W1 (mm) | A0 (mm) | B0 (mm) | K0 (mm) | P1 (mm) | W (mm) | Pin1 Quadrant |
|--------------|----------------|-----------------|------|------|--------------------|--------------------|---------|---------|---------|---------|--------|---------------|
| THS4021CDGNR | MSOP-Power PAD | DGN             | 8    | 2500 | 330.0              | 12.4               | 5.3     | 3.4     | 1.4     | 8.0     | 12.0   | Q1            |
| THS4021IDGNR | MSOP-Power PAD | DGN             | 8    | 2500 | 330.0              | 12.4               | 5.3     | 3.4     | 1.4     | 8.0     | 12.0   | Q1            |
| THS4021IDR   | SOIC           | D               | 8    | 2500 | 330.0              | 12.4               | 6.4     | 5.2     | 2.1     | 8.0     | 12.0   | Q1            |
| THS4022CDGNR | MSOP-Power PAD | DGN             | 8    | 2500 | 330.0              | 12.4               | 5.3     | 3.4     | 1.4     | 8.0     | 12.0   | Q1            |
| THS4022IDGNR | MSOP-Power PAD | DGN             | 8    | 2500 | 330.0              | 12.4               | 5.3     | 3.4     | 1.4     | 8.0     | 12.0   | Q1            |

## TAPE AND REEL BOX DIMENSIONS



\*All dimensions are nominal

| Device       | Package Type  | Package Drawing | Pins | SPQ  | Length (mm) | Width (mm) | Height (mm) |
|--------------|---------------|-----------------|------|------|-------------|------------|-------------|
| THS4021CDGNR | MSOP-PowerPAD | DGN             | 8    | 2500 | 358.0       | 335.0      | 35.0        |
| THS4021IDGNR | MSOP-PowerPAD | DGN             | 8    | 2500 | 358.0       | 335.0      | 35.0        |
| THS4021IDR   | SOIC          | D               | 8    | 2500 | 367.0       | 367.0      | 38.0        |
| THS4022CDGNR | MSOP-PowerPAD | DGN             | 8    | 2500 | 367.0       | 367.0      | 38.0        |
| THS4022IDGNR | MSOP-PowerPAD | DGN             | 8    | 2500 | 367.0       | 367.0      | 38.0        |

DGN (S-PDSO-G8)

PowerPAD™ PLASTIC SMALL OUTLINE



- NOTES:
- All linear dimensions are in millimeters.
  - This drawing is subject to change without notice.
  - Body dimensions do not include mold flash or protrusion.
  - This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 for information regarding recommended board layout. This document is available at [www.ti.com](http://www.ti.com) <<http://www.ti.com>>.
  - See the additional figure in the Product Data Sheet for details regarding the exposed thermal pad features and dimensions.
  - Falls within JEDEC MO-187 variation AA-T

PowerPAD is a trademark of Texas Instruments.



DGN (S-PDSO-G8)

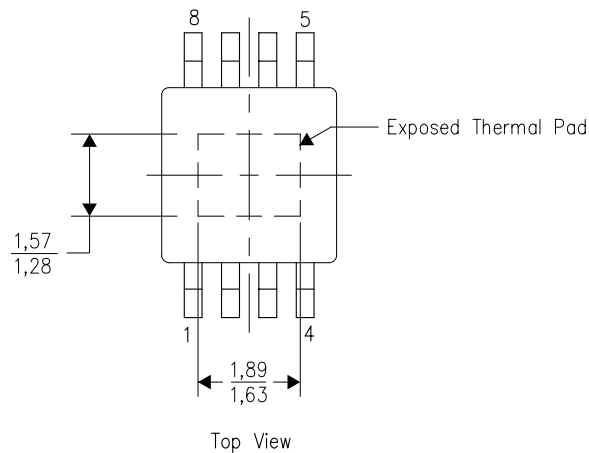
PowerPAD™ PLASTIC SMALL OUTLINE

## THERMAL INFORMATION

This PowerPAD™ package incorporates an exposed thermal pad that is designed to be attached to a printed circuit board (PCB). The thermal pad must be soldered directly to the PCB. After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For additional information on the PowerPAD package and how to take advantage of its heat dissipating abilities, refer to Technical Brief, PowerPAD Thermally Enhanced Package, Texas Instruments Literature No. SLMA002 and Application Brief, PowerPAD Made Easy, Texas Instruments Literature No. SLMA004. Both documents are available at [www.ti.com](http://www.ti.com).

The exposed thermal pad dimensions for this package are shown in the following illustration.



Exposed Thermal Pad Dimensions

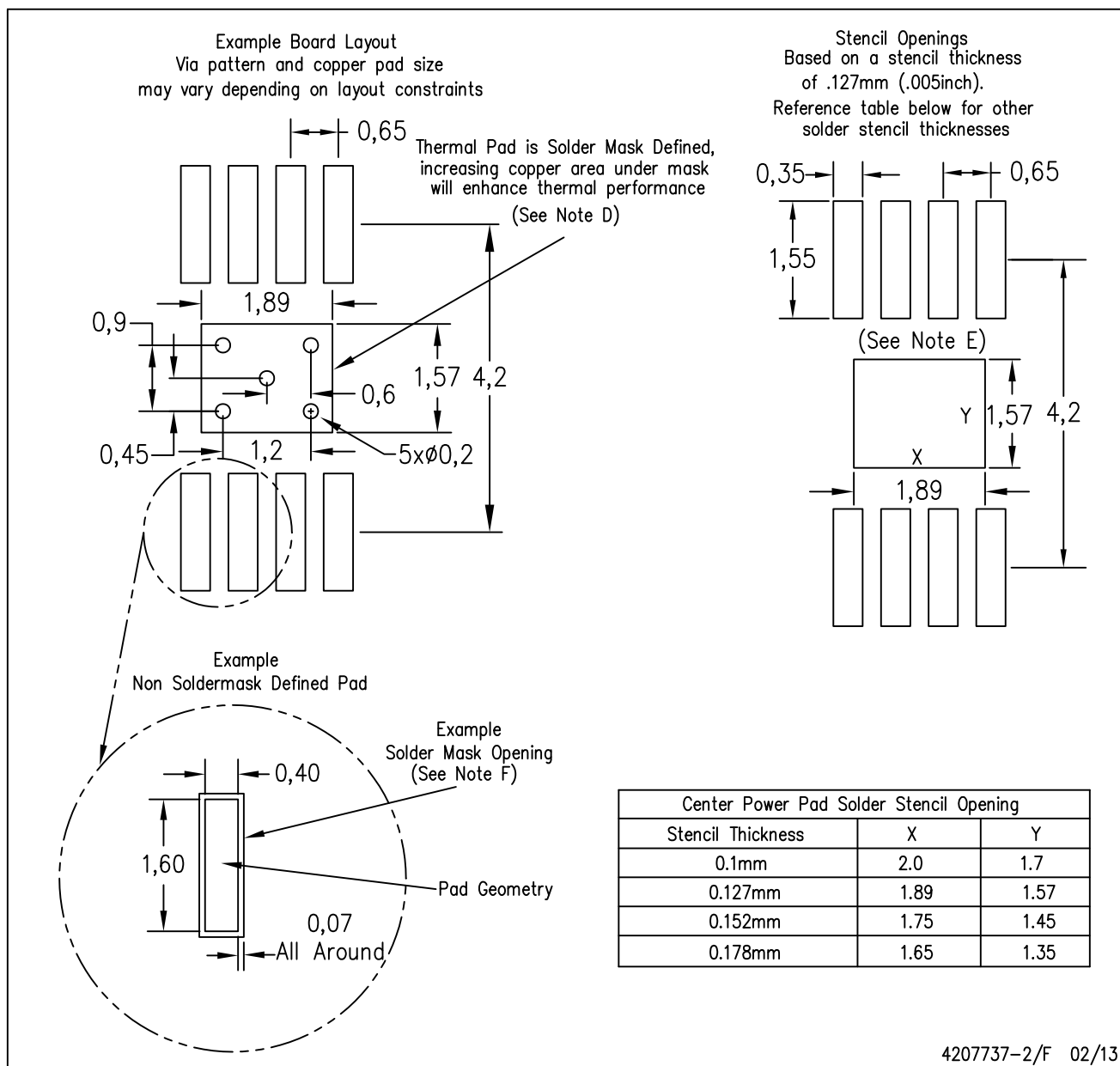
4206323-2/1 12/11

NOTE: All linear dimensions are in millimeters

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DGN (R-PDSO-G8)

PowerPAD™ PLASTIC SMALL OUTLINE



4207737-2/F 02/13

- NOTES:
- All linear dimensions are in millimeters.
  - This drawing is subject to change without notice.
  - Customers should place a note on the circuit board fabrication drawing not to alter the center solder mask defined pad.
  - This package is designed to be soldered to a thermal pad on the board. Refer to Technical Brief, PowerPad Thermally Enhanced Package, Texas Instruments Literature No. SLMA002, SLMA004, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at [www.ti.com](http://www.ti.com) <<http://www.ti.com>>.
  - Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Example stencil design based on a 50% volumetric metal load solder paste. Refer to IPC-7525 for other stencil recommendations.
  - Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

PowerPAD is a trademark of Texas Instruments

D (R-PDSO-G8)

PLASTIC SMALL OUTLINE



- NOTES:
- A. All linear dimensions are in inches (millimeters).
  - B. This drawing is subject to change without notice.
  - $\triangle C$  Body length does not include mold flash, protrusions, or gate burrs. Mold flash, protrusions, or gate burrs shall not exceed 0.006 (0,15) each side.
  - $\triangle D$  Body width does not include interlead flash. Interlead flash shall not exceed 0.017 (0,43) each side.
  - E. Reference JEDEC MS-012 variation AA.

D (R-PDSO-G8)

PLASTIC SMALL OUTLINE



4211283-2/E 08/12

- NOTES:
- A. All linear dimensions are in millimeters.
  - B. This drawing is subject to change without notice.
  - C. Publication IPC-7351 is recommended for alternate designs.
  - D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.
  - E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

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### Applications

|                               |                                                                                          |
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